Rehabilitation of an Old Concrete Lohse Arch Bridge
— Replacement of All Hanger of Kimitsu Shinbashi Bridge —

コンクリートローゼアーチ橋の補修
— 君津新橋の吊材取換 —


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Synopsis
The Kimitsu Shinbashi Bridge is a Lohse arch bridge with reinforced concrete arch ribs and prestressed concrete deck slab. On October 23, 2008, it was discovered that one of the 40 hangers connecting the arch ribs and deck slab had broken. The bridge was closed to traffic and breaking mechanism was followed by a detailed investigation. Repairs were effected step by step, ensuring the safety of the bridge throughout the process. This report describes the circumstances and procedures leading up to the replacement of hanger, and reports on the hanger replacement work utilizing newly developed tension releasing equipment.

Structural Data
Structure: Lohse arch bridge with reinforced concrete arch ribs and prestressed concrete deck slab
Bridge Length: 68.3m
Span: 66m
Width: 18.2m
Owner: Kimitsu City, Japan
Location: Chiba Prefecture, Japan

1. Introduction
The Kimitsu Shinbashi Bridge is concrete Lohse arch bridge constructed in 1973. It has a length of 68.3 m and a width of 18.2 m. The deck slab is supported by 40 hangers, arranged with pairs of steel bars (32 mm dia.) at 10 locations each on the upstream and downstream sides of the bridge. The original steel bars were coated with anti-corrosion paint, and then sheathed in stainless steel pipes. **Fig. 1** is an overall view of the retrofitted bridge.

Fig. 1 Retrofitted Kimitsu Shinbashi Bridge

2. Outline of Renewal Work
On October 23, 2008, it was discovered that one of the 40 hangers had broken. The bridge was closed to traffic and emergency repairs were performed to prevent the bridge collapsing, followed by permanent repairs including hanger replacement and seismic reinforcement. The repairs were completed and the bridge reopened to traffic on September 11, 2009, after being out of service for 11 months.

3. Investigation Cause of Break
(1) Emergency Investigation
An emergency investigation was performed immediately after break of the hanger, consisted of recovering the broken steel bar and visually inspecting

the extent of corrosion and the breaking section. The steel bar had broken close to a joint in the sheath pipe. As shown in **Fig. 2**, the anti-corrosive paint applied at the time of construction was peeling, and substantial corrosion had occurred, reducing tendon diameter from 32 mm to only 19 mm. The investigation on the other hangers revealed additional cases that the steel bars had reduced thickness due to corrosion, so the bridge was closed to traffic.

(2) Detailed Investigation

Detailed investigations were conducted to discover the cause of break of the steel bar. **Table 1** shows the items covered by the investigations, together with the results. Material tests on the steel bar did not find any abnormalities in terms of chemical constituents, metallographic structure, hardness, or tensile strength. Thus, it was judged that there were no deficiencies in terms of the materials. Furthermore, the examination of the broken surface suggested that rather than ductile fracture, this breaking was a brittle fracture starting at the section where the surface was corroded.

Next, because of conspicuous reduction in thickness of the broken steel bar due to corrosion, electrical continuity between the steel bar and stainless steel sheath pipe was tested in situ. This test showed that although there was no continuity at the points on the steel bar where the coating remained, there was electrical continuity when the coating was removed.

From the results of these investigations, it was surmised that the joint between sheath pipes protecting the steel bar separated due to degradation and vibration. In addition, dissimilar metal corrosion occurred due to partial electrical contact between the stainless steel sheath pipe/sleeve and the steel bar, and that the steel bar subject to conspicuous reduction of cross-section lost resistance capacity and had broken. This corrosion mechanism is illustrated in **Fig. 3**.

Fig. 2 Broken steel bars

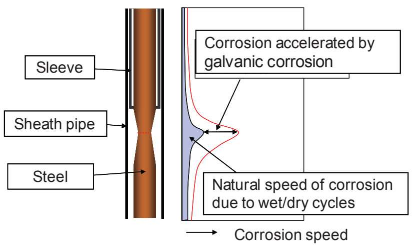

Fig. 3 Corrosion mechanism

Table 1 Detailed investigation of steel bars

	Tests	Results
Material tests	Appearance	Section reduced to 35% at point of breaking
	Chemical constituent analysis	JIS standards compliant
	Metal structure observation	OK
	Hardness measurement	OK
	Tensile test	JIS standards compliant
Dissimilar metals corrosion testing	Galvanic corrosion test	Corrosion likely (Corrosion current density : 20μA/cm^2)

4. Outline of Repair Work

(1) Emergency Repairs

The emergency repairs are illustrated in **Fig. 4**.

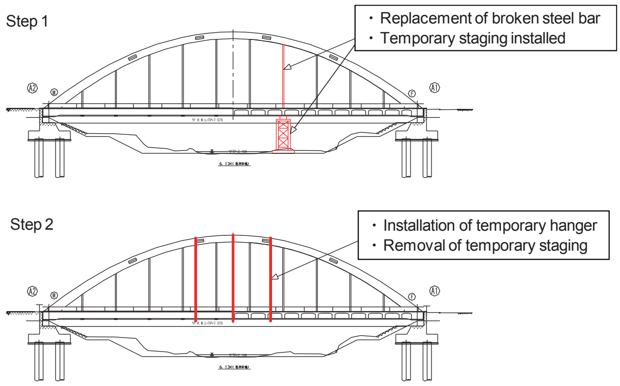

Fig. 4 Outline of emergency repairs

1) Emergency Repairs: Step 1

Step 1 of the emergency repairs envisaged potential break of the steel bars adjacent to the broken steel bar. As a precautionary measure, a temporary staging was directly installed under the broken steel bar to support the deck slab of the bridge, and the broken steel bar was replaced. The existing coupler embedded in the deck slab was not corroded, so after testing its load capacity, it was reused when replacing the steel bar, connecting a new tendon to the coupler. The temporary staging was constructed by using large sandbags to make a coffer dam in the river, then assembling steel staging materials on a concrete foundation.

2) Emergency Repairs: Step 2

Step 2 of the emergency repairs consisted of temporary installing 12 additional hangers with the objective of ensuring structural integrity and preventing the bridge from collapsing in the event of break of up to 24 steel bars, equivalent to 60% of the hangers. The structure of the temporary hanger consisted of steel support beams secured to the top surface of the arch ribs and to the bottom surface of the deck slab, with these beams linked by new steel bars. Out of consideration for the overall balance of the structure and in order to facilitate the work of hanger replacement at the permanent repair stage, these temporary members were positioned midway between existing hanger. It was necessary to drill through the deck slab to accommodate the additional steel bars. As there was a risk that drilling might damage nearby longitudinal prestressing cables or steel reinforcements, X-ray inspection and ground-penetrating radar were used to locate steel elements before starting work, and the drilling was performed cautiously to prevent damage. Installation of the temporary members made it possible to remove the temporary staging from the river, ensuring the safety during the flood season.

(2) Permanent Repairs

1) Outline of Permanent Repairs

The permanent repairs consisted of replacement of the hangers. Prestressing cables were used instead of the original steel bars, because they provided the superior fatigue and corrosion performance, also enhance durability and meet the load performance and seismic performance criteria required by the current Specifications for Highway Bridges. The permanent repairs are illustrated in **Fig. 5**.

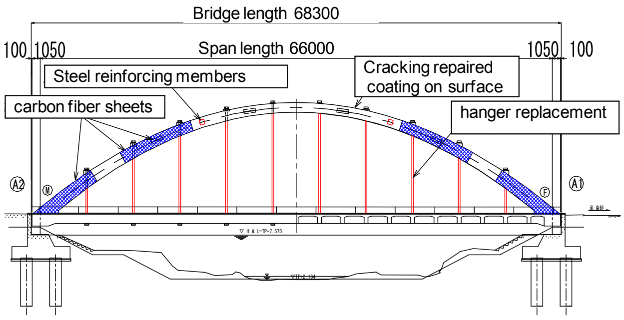

Fig. 5 Outline of permanent repairs

2) Hanger Replacement Work

Since the cause of break of the hanger was corrosion, it was decided to replace the steel bars with prestressing cables. The cables have a dual protective coating, provide greater corrosion performance, and moreover, meet current standards. To enhance further corrosion performance, anchorages were sprayed with zinc-aluminum pseudo alloy, and anchorage covers were filled with polyurethane resin to prevent infiltration of rainwater, etc.

Replacement of hanger began with the hanger in the center of the span where corrosion was most severe and bar thickness was most reduced. Then, the process moved towards the ends of the bridge, replacing the two members at each location together. The replacement process is as follows.

1. Releasing the tension from the existing steel bars.
2. Removing the old bars.
3. Core drilling the arch ribs and deck slab.
4. Installing the new cables and tensioning them to the design tension for the old hanger.

Hanger replacement is illustrated in **Fig. 6**.

Tension in existing steel bars is usually released by fitting jacks to the ends of the bars at the anchorages. However, for this project, because the length at the ends was insufficient for the threading required, tension was released using specially developed tension releasing equipment attached partway up the member. The tension releasing equipment was performance tested to confirm its safety and efficiency before being used.

5. Development of Tension Releasing Equipment

The old hanger on this bridge did not have sufficient

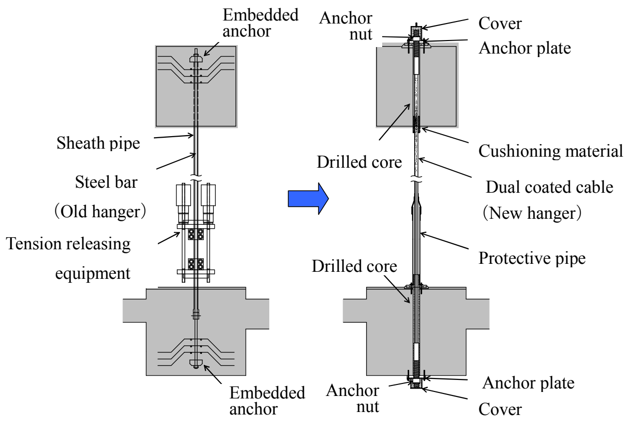

Fig. 6 Replacement hangers

length at the anchorages for releasing tension. For this reason, there was a need for a system that could reliably attach to the steel bar under tension and release the tension safely. The following issues were considered with regard to releasing the tension.

a. Development of a reliable system for attaching the equipment and diverting the existing tension

b. Shock-free method for safely cutting steel bar

c. Method for releasing tension while minimizing increase in tension on old hanger

d. Method for minimizing increase in tension on other hanger

Tension releasing equipment using wedge anchorage devices was developed as a system to meet all these requirements. The equipment is illustrated in **Fig. 7**.

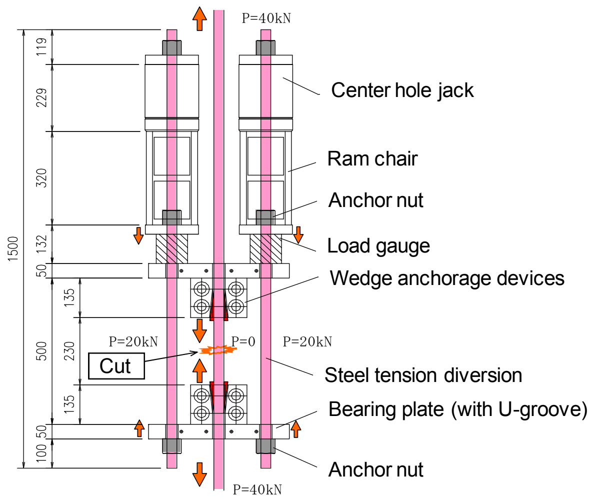

Fig. 7 Tension releasing equipment

The anchorage wedges and anchorage cones both have a two-part structure so that they can be easily attached wherever required. The steel tension diversion bars were fitted with hydraulic jacks and load gauges. The procedure for releasing tension is as follows.

- Fit the wedge anchorage devices to the old steel bar, and put the tension releasing equipment in position.
- Use the two hydraulic jacks to tension the steel tension diversion bars. The tension is transferred

to the old steel bar through the bearing plates and anchorage wedges, releasing the tension in the steel bar between the wedges.

- Cut the old steel bar between the anchorage wedges with a gas cutter. The tension between the wedge anchorage devices is transferred to the tension diversion bars.
- Slowly release the hydraulic jacks. The tension is released over the whole length of the steel bar.

Before using the tension releasing equipment on the site, it was tested its performance to confirm its safety and efficiency.

6. Loading Test

Loading tests of the actual bridge were performed to confirm the effects of repairs and reinforcements, and to provide data for use as a benchmark in future detailed investigations. In the loading tests, loading vehicles were placed on the bridge deck, and measurements taken of strain in the arch ribs/deck slab, deck slab deflection, and tension of hanger. These measurements were compared with the calculated estimates to confirm the load capacity of the bridge after reinforcement. Three vehicles of 196 kN each were used as the loading vehicles, taking measurements for 6 different cases. The estimates were produced by 3D framework analysis.

The results of measurement for the case of loading at 1/4 span are shown in **Fig. 8**. The graph on the left shows the deflection of the deck slab under load. The measurements of deck slab deflection and strain in the arch ribs and deck slab matched well with the calculated estimates, confirming that the required flexural stiffness and load carrying capacity have been achieved. The distribution of strain in the arch ribs and deck slab was consistent with Bernoulli-Euler model assumptions, confirming that each of the members was behaving as an elastic body.

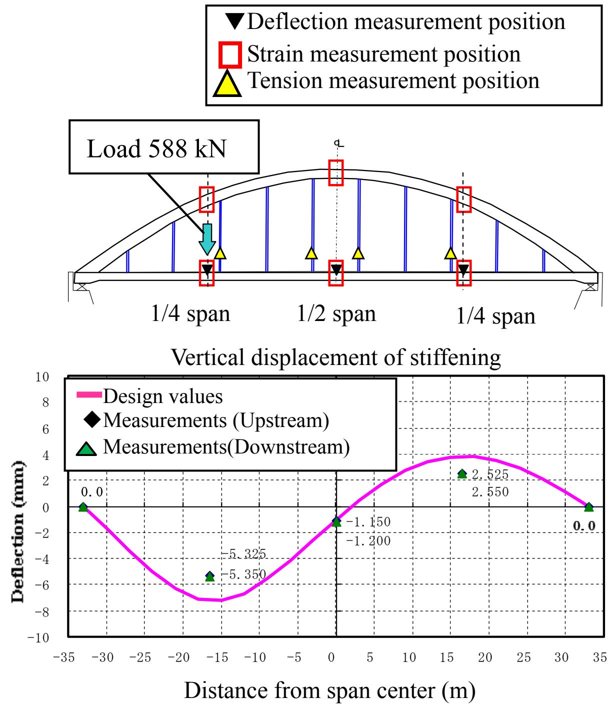

Fig. 8 Results of loading test on bridge after repairs

7. Conclusions

This repair project has three major characteristics.

1. Tension releasing equipment was specially developed for the old steel bar, and subjected to performance testing before use on the bridge.
2. Variations in tension of the old hanger and displacement of the bridge were measured in real time, constantly confirming safety as the work progressed.
3. As a solution to maintenance, hanger tension was measured and loading tests was performed, producing data that can be a benchmark for future detailed investigations.

This paper describes an example of maintenance procedures to extend the service life of a bridge, a requirement that is likely to become increasingly common in the future.

References

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概　要

君津新橋は，RC 製のアーチリブと PC 製の下弦材から構成されている下路式コンクリートローゼアーチ橋である。2008年10月23日，アーチリブと下弦材を繋ぐ吊材40本のうち１本が破断しているのが発見され，車両通行止めの措置がとられた。その後ただちに，緊急・詳細調査および原因究明を進めるとともに橋梁の安全性を確保しながら段階的に補修工事を実施した。

工事においては，既設 PC 吊鋼材の緊張力解放装置を新たに開発し，事前性能確認試験を踏まえて実橋に適用した。また，既設吊材緊張力変動や橋体変位をリアルタイムに計測し，安全性を確認しながら施工した。吊材 PC 鋼材破断という不測の事態により車両通行止めを行ったが，工事を安全に施工するための新技術開発やモニタリングシステムの活用により，無事故で早期復旧を実現した。